EXHIBIT N

Aesthetic Measures for Assessing Graphic Screens

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An important aspect of screen design is aesthetic evaluation of screen layouts. However, no one knows how to measure aesthetic value. This article proposes a theoretical approach to capturing the essence of the artists' insight. We introduce several aesthetic measures for graphic screens. The results of our informal study demonstrate close relationships between artistic vision and the proposed measures.

Keywords: screen design, interface aesthetics, aesthetic measures, aesthetic characteristics, multi-screen interfaces
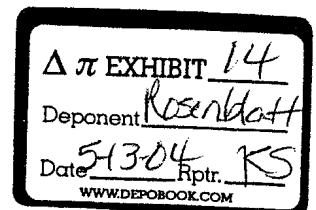
1. INTRODUCTION

One way to enhance the usability of a computer system is to improve the appearance of the user interface. The research reported here concerns making computers easier to use by improving interface aesthetics.

Users are frustrated with many unusable products they have to deal with in their day-to-day lives. Newsmagazines, newspapers, and books report growing dissatisfaction with unusable products [1]. Use of a screen, and a system, is affected by a variety of factors. Included are how much information is presented on the screen, how the screen is organized, the language used on the screen, the distinctiveness of the screen's components, and provision of proper feedback. Among these factors, one very essential component of graphical user interface design concerns the actual layout of elements on the screen. This is a realm of graphical design that has been missed by today's HCI researchers. To achieve the ultimate goal of designing an acceptable system, a more balanced approach may be needed.

Many of the low-level concerns of implementation have been eliminated through the introduction of predefined screen elements and palettes that allow for a pick-and-choose approach to design. This allows more attention to be focused on the organization and structure of interfaces, areas where design expertise should be focused. Due to the lack of formal design models, there are few supporting tools available for these areas.

The goals of this paper are to promote the importance of aesthetics in computer systems, to compile a list of relevant aesthetic considerations, and to incorporate them into a computational model. The paper begins with the motivation view and a presentation of related

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research. Section 3 introduces a new aesthetic model. Then, sections 4 and 5 present preliminary studies on the model. Section 6 outlines an example application where the model has been installed as part of an evaluation tool. Finally, the findings are summarized and the contributions reviewed.

2. BACKGROUND

One way to make products easier to use, and users more productive, is to improve the visual communication that takes place in all of the elements of the UI: metaphors, mental models, navigation schema, look, and feel [2]. Recent research on these elements shows great maturity. For example, the desktop metaphor and its composites have been the most successful and pervasive of all interface metaphors. There are other metaphors which have been developed for applications other than information systems [3.1]. Screen-based controls are the elements of screens that permit the user to interact with data. Check boxes, sliders, menus and buttons are all examples of interface components. It is possible to identify basic interface components that nearly all windowing systems have in common [3.2]. There are standard navigation models for different applications. Document-centric MDIs (multi-document interfaces like Microsoft Word) typically have the daisy-style navigation model [4.1]. People form mental models through experience, training and instruction [1, 3. 3]. We do know a great deal about how to figure out what ideas will already be familiar to users, how to identify the underlying ideas of a program, and how to use that knowledge to produce a better design [4.2, 3.4].

The element look (beauty) has not been properly documented in recent years. One study [5] has shown that the HCI literature in general, and that on usability in particular, has mostly neglected the aesthetics issue completely. For example, the indices of four prominent HCI textbooks and reading collections [3, 6-8] do not contain a single entry for "aesthetics" (or synonyms and related concepts, such as "appearance," "attractiveness," "beauty" or "form"). Thus, it would appear that mainstream HCI has either belittled the importance of aesthetics or ignored it altogether. Are we missing an important point here?

Aesthetics may not be the only solution, but it definitely plays a significant role in the overall value of screen design. The role of aesthetics in human affairs has been widely documented [9]. Certainly, it is related to our appreciation of computer systems as well. However, some [10, 11] have warned against a tendency among designers to emphasize the aesthetic elements of the user interface because they might degrade usability. In fact, interface aesthetics play a greater role in system usability and acceptability than we might be willing to admit. Two recent studies found very high correlations between users' perceptions of interface aesthetics and of usability. In the second study [5], three experiments were conducted to validate and replicate, in a different cultural setting, the results of the first [12], a study obtained by Kurosu and Kashimura concerning the relationships between users' perceptions of interface aesthetics and usability. The results support the basic findings by Kurosu and Kashimura. Very high correlations were found between the perceived aesthetics of the interface and the priori perceived ease of use of the system. Another study [13] found that good aesthetic layouts have a definite effect on a student's motivation to learn based on the ARCS model [14]. In particular, the study discovered that:

- A = Attention (good layouts will attract the attention of the student);
- R = Relevance (good layouts will be relevant to the student);
- C = Confidence (good layouts will boost the student's confidence);
- S = Satisfaction (the student will feel satisfied if the design is good and appealing).

There should be a system of methods and principles for evaluating interface aesthetics. However, today's techniques account only for usability measurement. Tullis [15] developed four metrics for alphanumeric displays: overall density, local density, grouping, and layout complexity. Streveler and Wasserman [16] proposed a measure of "balance" as one of their objective techniques for assessing the spatial properties of screens. Sears' [17] developed a task-dependent metric called layout appropriateness to assess whether the spatial layout is in harmony with the user's tasks. Framer [18] proposed a small rule base with design knowledge about relevant aspects of user interfaces. The Praise command tells a user the positive aspects of a design; the Suggest Improvements command criticizes the design; the Explain option gives some rationale for the suggested improvement.

No one knows how to measure aesthetic value. Some [19, 20.1] even doubt that it can be measured. This article reports a set of metrics that captures the essence of the artist's insight in order to complement the above measures. We define five aesthetic measures for graphic displays: balance, equilibrium, symmetry, sequence, and order and complexity. (Previous related papers are [21, 22].) The notion of what is artistic has evolved throughout history. Graphic design experts have, through perceptual research, derived a number of principles for defining what comprises a visually pleasing appearance [20, 23-27]. This article relies heavily on these works to help demonstrate our approach.

There are four basic ways to use windows [4.3]:

- multi-window interfaces: examples are the IBM OS/2 operating system, most UNIX X-windows applications, and now Microsoft Windows 98;
- multi-document interfaces: for example, Microsoft Word or Excel;
- multi-pane interfaces: Microsoft Paint and Netscape Navigator are examples;
- multi-screen interfaces: mostly found in one-time GUIs and wizards, and multimedia applications.

This article primarily addresses multi-screen interfaces. With some modification, some of the techniques presented can also be used for other screen types. Keep in mind that the following discussion does not focus on the words on the screen, but on the perception of structure created by such elements as spacing and objects.

3. AESTHETIC MEASURES

This section briefly defines the measures of balance, equilibrium, symmetry, and sequence. It also shows how the measure of screen order and complexity is derived from them.

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3.1 Aesthetic Measure of Screen Balance

Balance on a screen is accomplished by centering the layout, thus maintaining an equal weighting of components on each side of the horizontal and vertical axis. It does not have to be static balance which is symmetry; it can equally well be dynamic balance which is asymmetry.

The formula is

$$BM = (w_L - w_R, \; w_T - w_B), \tag{1}$$

where BM is the measure of balance, w_L is the weight on the left hand side (LHS), w_R is the weight on the right hand side (RHS), w_T is the weight on the top, and w_B is the weight on the bottom.

The weight of a layout is the algebraic sum of the weight of its components:

$$w = \sum_i a_i d_i, \tag{2}$$

where a_i is the area of an object and d_i is the distance between its vertical central line and the vertical axis. Consider the layout shown in Fig. 1.
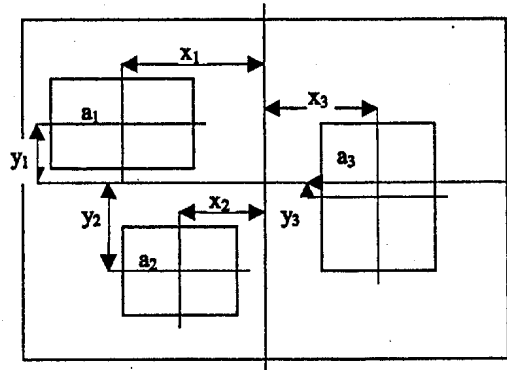

Fig. 1. A balanced screen layout.

In Fig. 1, we obtain from Eq. 2

$$w_L = a_1 x_1 + a_2 x_2,$$
$$w_R = a_3 x_3,$$
$$w_T = a_1 y_1,$$
$$w_B = a_2 y_2 + a_3 y_3.$$

If

$$BM = (0, 0), \qquad \text{(from Eq. 1)}$$

then the layout is in a state of balance.

If

$$w_L - w_R > 0,$$

then the LHS is heavier than the RHS.
If

$$w_L - w_R < 0,$$

then the RHS is heavier than the LHS.
If

$$w_T - w_B > 0,$$

then the top is heavier than the bottom.
If

$$w_T - w_B < 0,$$

then the bottom is heavier than the top.

Visual balance may be achieved through symmetry or asymmetry. A balanced display creates a feeling of stability and confidence in a viewer while an unbalanced display creates a feeling of stress [19].

3.2 Aesthetic Measure of Screen Equilibrium

Equilibrium can be defined as equal balance between opposing forces. Any visual object constitutes a center of forces. The interplay between various visual objects as centers of forces is the basis of composition. A layout is in equilibrium when its center coincides with the center of the frame. (There are minor deviations, which we will discuss in section 7.)

The formula is:

$$EM = (x_c, y_c) - (x_0, y_0)$$

or

$$EM = (x_c - y_0) - (y_c - y_0), \tag{3}$$

where EM is the measure of equilibrium, (x_0, y_0) is the center of a layout, and (x_c, y_c) is the center of the frame. The center of a set of objects of areas $a_1, a_2, a_3...$ at points (x_1, y_1), (x_2, y_2), $(x_3, y_3)...$ in the xy plane is

$$(x_0, y_0) = \left(\frac{\sum_i a_i x_i}{\sum_i a_i}, \frac{\sum_i a_i y_i}{\sum_i a_i} \right). \tag{4}$$

This is based on the formula for the center of gravity of a set of particles in a plane. Consider the layout shown in Fig. 2.

In Fig. 2, we obtain from Eq. 4

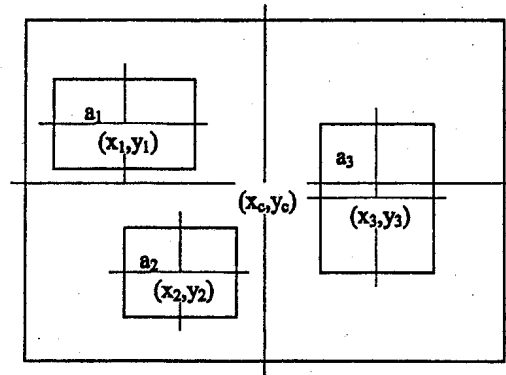102   DAVID CHEK LING NGO, AZMAN SAMSUDIN AND ROSNI ABDULLAH

Fig. 2. A screen layout in equilibrium.

$$x_0 = \frac{a_1 x_1 + a_2 x_2 + a_3 x_3}{a_1 + a_2 + a_3}$$

and

$$y_0 = \frac{a_1 y_1 + a_2 y_2 + a_3 y_3}{a_1 + a_2 + a_3}.$$

For equilibrium,

$$EM = (0, 0) \qquad \text{(from Eq. 3)}$$

Equilibrium and balance are the same when either conditions $x_c = x_0$ and $y_c = y_0$ or $w_L = w_R$ and $w_T = w_B$ (from Eq. 1) are fulfilled. This can be illustrated as follows:

For an equal weighting of screen components on each side of the vertical axis, we have

$$x_c = x_0$$

and

$$w_L = w_R.$$

For an equal weighting of screen components on each side of the horizontal axis, we have

$$y_c = y_0$$

and

$$w_T = w_B.$$

If

$$EM = (0, 0),$$

then

$BM = (0, 0);$ (from Eq. 1)

thus,

$EM = BM.$

As long as the centers of a configuration are in perfect equilibrium, the whole is in a state of repose. Otherwise, strong incompatibility will develop, and the viewer will a faced with a contradiction between the different centers.

3.3 Aesthetic Measure of Screen Symmetry

Symmetry is the balanced distribution of equivalent elements about a common line. Vertical symmetry refers to the balanced arrangement of equivalent elements about a vertical axis, and horizontal symmetry refers to the balanced arrangement of equivalent elements about a horizontal axis. Radial symmetry consists of equivalent elements balanced about two or more axes that intersect at a central point.

The formula is:

$$SM = \{[g_{UL} - g_{LL}], [g_{UR} - g_{LR}], [g_{UL} - g_{UR}], [g_{LL} - g_{LR}], [g_{UL} - g_{LR}], [g_{UR} - g_{LL}]\}, \quad (5)$$

where SM is the measure of symmetry, g_{UL} is the weight on the upper-left quadrant, g_{UR} is the weight on the upper-right quadrant, g_{LL} is the weight on the lower-left quadrant, and g_{LR} is the weight on the lower-right quadrant.

The weight of a layout is the algebraic sum of the weight of its components:

$$g = \sum_i (|x_i - x_c|, |y_i - y_c|, l_i, b_i), \quad (6)$$

where l_i is the length of an object, b_i is the breadth of the object, (x_i, y_i) is the center of the object, and (x_c, y_c) is the center of the frame. (Note the difference between Eq. 6 and Eq. 2. We define different weight measures for different purposes. We use Eq. 6 for the symmetry measure and Eq. 2 for the balance measure.)

Consider the layout shown in Fig. 3.

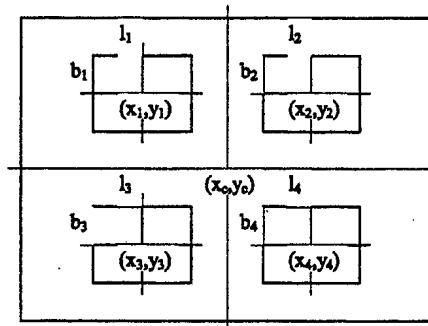In Fig. 3, we obtain from Eq. 6

Fig. 3. A symmetrical screen layout.

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$$g_{UL} = (|x_1 - x_c|, |y_1 - y_c|, l_1, b_1),$$
$$g_{UR} = (|x_2 - x_c|, |y_2 - y_c|, l_2, b_2),$$
$$g_{LL} = (|x_3 - x_c|, |y_3 - y_c|, l_3, b_3),$$
$$g_{LR} = (|x_4 - x_c|, |y_4 - y_c|, l_4, b_4).$$

For vertical symmetry,

$$g_{UL} - g_{UR} = (0, 0, 0, 0),$$
$$g_{LL} - g_{LR} = (0, 0, 0, 0). \qquad \text{(from Eq. 5)}$$

For horizontal symmetry,

$$g_{UL} - g_{LL} = (0, 0, 0, 0),$$
$$g_{UR} - g_{LR} = (0, 0, 0, 0).$$

For radial symmetry,

$$g_{UL} - g_{LR} = (0, 0, 0, 0),$$
$$g_{UR} - g_{LL} = (0, 0, 0, 0).$$

In screen composition, symmetry can be used to organize the components. Symmetry creates balance; however, the difference is that balance can be achieved without symmetry.

3.4 Aesthetic Measure of Screen Sequence

Sequence refers to the arrangement of objects in a layout in a way that facilitates eye movement. Normally the eyes, trained by reading, start from the upper left and move back and forth across the display to the lower right. Streveler and Wasserman [16] found that visual targets located in the upper-left quadrant of a screen were found fastest, and that those located in the lower right quadrant took longest to find. By manipulating eye attractors, we can plan how information in a display will be ordered for use.

To find a visual path in a layout,
1. start from an eye attractor;
2. move to an adjacent attractor on the same level or the level below;
3. repeat 2 until the last node is reach.

The attractiveness of an object depends on its weight, which is given by

$$a \times q,$$

where a is the area of the object and q is the value of the quadrant in which the object resides. q_{UL} (the upper-left quadrant) equals 4, q_{UR} (the upper-right quadrant) equals 3, q_{LL} (the lower-left quadrant) equals 2, and q_{LR} (the lower-right quadrant) equals 1. The greater the weight is, the more attractive the object is.

A complete path is a path that exists from the upper-left quadrant of the screen to the bottom-right quadrant. The length of a path is the number of edges. A short path is more desirable than a longer one. An optimal layout is a layout that facilitates eye the movement and minimizes visual scanning. If users can move through a display in a left-to-right, top-to-bottom manner with few visual targets, then faster performance is likely, compared to the case where the layout requires numerous jumps between widely separated parts of the display.

The formula is given by

$$SQM = (p, d) \tag{7}$$

with the following definitions:

$$p = \begin{cases} 1, & \textit{if a path exists} \\ 0, & \textit{otherwise,} \end{cases}$$
$$d = n_e,$$

where SQM is the measure of sequence, p is the existence of a complete path, d is the length of the path, and n_e is the number of edges.

For optimal layouts,

$$SQM = (1, \leq 3).$$

Consider the layout shown in Fig. 4. Is there a path from the upper-left quadrant to the bottom-right quadrant? What is the distance?
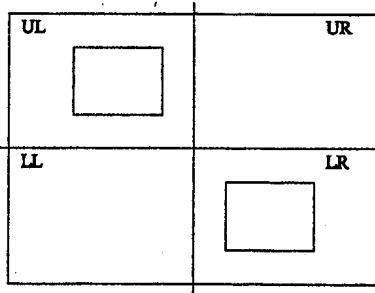

Fig. 4. A screen with a sequential layout.

In Fig. 4, we obtain from Eq. 7

$$SQM = (1, 1).$$

Conforming to the findings of eyeball fixation studies, the measure encourages a normal reading pattern so as to guide the eyes through the screen in a logical, rhythmic order. This approach will permit left-to-right, top-to-bottom reading as is common in Western cultures. The opposite of sequence is chaos, where a flow cannot be detected [25].

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3.5 Aesthetic Measure of Screen Order and Complexity

The measure of screen order and complexity follows from a well-known measure of aesthetic value given by Birkhoff [28] based on the formula:

$$M = \frac{O}{C},\qquad\qquad(8)$$

where M is the measure of order and complexity, O is the order of an object in a certain class of objects, and C is the complexity of the object in that class.

The aesthetic demand for "unity in variety" is closely related to this formula; unity is associated with order and variety with complexity. Birkhoff applies his formula to several classes of objects: polygons, ornaments and tilings, vases, simple musical pieces, and poetry by giving explicit conventions for measuring the order and complexity of objects in each of these classes. We interpret this formula for screen design. The order O of a screen layout is defined as:

$$O = O_{BM} + O_{EM} + O_{SM} + O_{SQM},\qquad\qquad(9)$$

where O_{BM} is a measure of balance, O_{EM} is a measure of equilibrium, O_{SM} is a measure of symmetry, and O_{SQM} is a measure of sequence. The complexity C of a layout is defined as the number of its components. More precisely, the conventions for determining the properties of a layout are as follows. The formula is:

$$M = \frac{O_{BM} + O_{EM} + O_{SM} + O_{SQM}}{C}(C > 0)\qquad\qquad(10)$$

with the following definitions.

$$O_{BM} = \begin{cases} 0.5, & if\ w_L = w_R\ and\ w_T = w_B \quad (from\ Eq.1) \\ 0.25, & if\ w_L = w_R\ or\ w_T = w_B \\ 0, & otherwise, \end{cases}$$

$$O_{EM} = \begin{cases} 0.5, & if\ x_c = x_o\ and\ y_c = y_o \quad (from\ Eq.3) \\ 0.25, & if\ x_c = x_o\ or\ y_c = y_o \\ 0, & otherwise, \end{cases}$$

$$O_{SM} = \begin{cases} 1.5, & \begin{aligned} &if\ (g_{UL} = g_{UR}\ and\ g_{LL} = g_{LR})\ and \\ &(g_{UL} = g_{LL}\ and\ g_{UR} = g_{LR})\ and \quad (from\ Eq.5) \\ &(g_{UL} = g_{LR}\ and\ g_{UR} = g_{LL}) \end{aligned} \\ 1, & \begin{aligned} &if\ (g_{UL} = g_{UR}\ and\ g_{LL} = g_{LR})\ and \\ &(g_{UL} = g_{LL}\ and\ g_{UR} = g_{LR}) \end{aligned} \\ 0.5, & \begin{aligned} &if\ (g_{UL} = g_{UR}\ and\ g_{LL} = g_{LR})\ or \\ &(g_{UL} = g_{LL}\ and\ g_{UR} = g_{LR})\ or \\ &(g_{UL} = g_{LR}\ and\ g_{UR} = g_{LL}) \end{aligned} \\ 0, & otherwise, \end{cases}$$

$$O_{SQM} = \begin{cases} 0.5, & if\ SQM \geq 5\ (from\ Eq.7) \\ 0, & otherwsie. \end{cases}$$

Notice that different order factors have different ranges, depending on their degree of importance. Since balance and equilibrium are closely related to each other (see section 3.2), they form a collective factor with a range between 0 and 1. According to experts, the order of significance from most to least is symmetry, balance (or equilibrium) and sequence. Therefore, the weighting criteria for symmetry and sequence are 1.5 and 0.5, respectively. The range of the measure is from 0 to 3. This measure is an aggregate of the aesthetic measures discussed in the previous sections. Fig. 5 shows the graph of the equation. Note that M decreases as C increases.
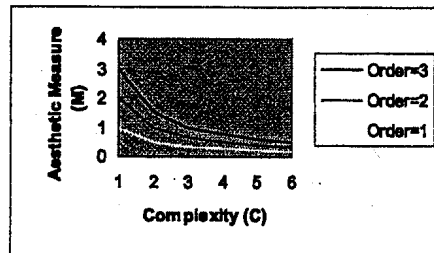

Fig. 5. The graph of Eq. 10.

With order, the objects are seen as forming one piece. The way to maximize screen order is to achieve balance, equilibrium, symmetry, and sequence while the way to minimize screen complexity is to reduce the number of screen objects. However, there must be at least one object in order to do anything useful.

4. PENCIL-AND-PAPER STUDY

We have applied the measure of screen order (Eq. 9) to a set of two-object layouts as shown in Fig. 6. Our study, by way of illustration, used simple, artificial displays. The findings from this study can be easily generalized to complex, real-world displays. (Note that Eq. 9, the numerator of Eq. 10, is used here instead of Eq. 10 as it is easier to work with integers than fractions, and that since the denominator of Eq. 10, C, remains constant in this study, it is insignificant anyway.) The results are given in Table 1. L1 and L2 are in balance and equilibrium. Both are symmetrical about a horizontal axis and a vertical axis. L3 and L4 are partially in balance and equilibrium. Their balancing centers do not coincide with the center of the screen; they are either far above or below the center of the screen. L3 and L4 are symmetrical about a vertical axis. L5 is in balance and equilibrium, and is radially symmetrical. L6 and L7 are partially in balance and equilibrium, and are asymmetrical. The arrangement of objects in each layout provides sequence except in L4. On the whole, L1, L2 and L5 were measured high, and L3, L4, L6 and L7 were measured low.
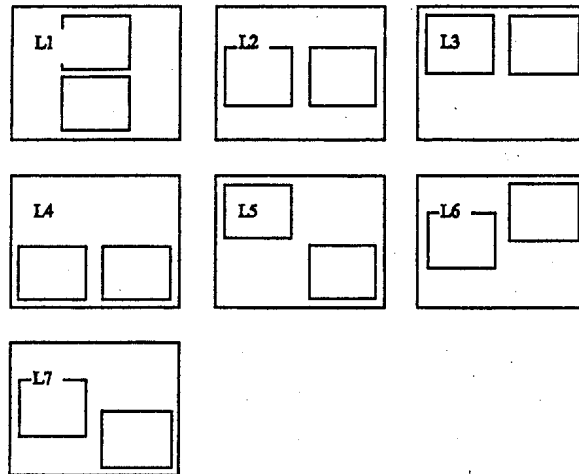
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Fig. 6. A set of two-object layouts.

Table 1. Computation of aesthetic value for the layouts shown in Fig. 6 using Eq. 9.

Layout	O_{BM}	O_{EM}	O_{SM}	O_{SQM}	O
L1	0.5	0.5	1	0.5	2.5
L2	0.5	0.5	1	0.5	2.5
L3	0.25	0.25	0.5	0.5	1.5
L4	0.25	0.25	0.5	0	1
L5	0.5	0.5	0.5	0.5	2
L6	0.25	0.25	0	0.5	1
L7	0.25	0.25	0	0.5	1

5. EMPIRICAL STUDY

The objectives of this exercise are to establish aesthetic values for a set of screen layouts using our measures for comparison with the corresponding subjects' scores, and to see how consistent they are. Our study consisted of two tests. In the first test, we explored the relationships between our aesthetic measures and artists' aesthetic perceptions. The second test was designed to test the robustness of the findings. A group of six GUI designers working at a multimedia company in Ireland participated in the first test, and a different group of twenty-two engineering undergraduates studying at a science university in Malaysia participated in the second test. Seven layout patterns, which included the same components and differed only in how these components were arranged, were evaluated with respect to aesthetics. The subjects were asked to rate this aspect using three point rating scale, i.e., to rate how beautiful they looked. The unique aspects of each test and the main results are described below.

The 7 layouts in Fig. 6 were first shown to each designer in hard copy form, and the designer rated each layout based on a 0 (worst) to 3 (best) scale regarding how beautiful it looked. The results are presented in Table 2 alongside the corresponding aesthetic values from Table 1. Designer D6 committed himself on layout L5 only.

Table 2. Rating scores of the layouts in Fig. 6 given by 6 GUI designers.

	D1	D2	D3	D4	D5	D6	Mean	O
L1	2	2	2.5	2.5	1.5	N/A	2.1	2.5
L2	3	3	2.5	2.5	2	N/A	2.6	2.5
L3	2	2	0	1	1.5	N/A	1.3	1.5
L4	1	1	0	1	1	N/A	0.8	1
L5	2	2	2	3	2.5	3	2.4	2
L6	0	2	0	0	1	N/A	0.6	1
L7	0	1	1.5-2	0	1.5	N/A	0.8	1

On average, L1, L2 and L5 were rated high, and L3, L4, L6 and L7 were rated low, which agreed with their computed values. However, there were some discrepancies between the designers. Layout L1, which was measured high, was rated low by designer D5. He commented that although the layout was "nice," its aspect ratio did not resemble the aspect ratio of the frame. Changing the aspect ratio of a visual field may affect eye movement patterns, which, in turn, may confuse the user. Layout L3, with a low aesthetic measure, was rated high by designers D1 and D2. They pointed out that the placement of the objects in the layout provided an obvious starting point in the upper-left corner of the screen, which was where visual scanning began, and also that the balancing center of the objects was above rather than below the center of the frame, which gave the viewer a sense of stability (see section 7 for an explanation). Layout L6, with a low aesthetic measure, was rated high by designer D2. According to him, the layout was dynamic as opposed to monotonous. The layout contained two objects lined up in a sloping line, which provided an impression of movement.

By and large, the designers' scores for the layouts were consistent with their aesthetic values. This can be seen in Fig. 7, which plots the computed versus the designers' data from Table 2. Note that the scattergram suggests a linear relationship between the two rankings.

The coefficient of correlation is $r_s = 0.99$. Thus, the designers' scores and the computed values are very highly correlated-at least for the sample of 7 layouts we studied.

The second part of the experiment was designed to test the robustness of the findings. Participants were 22 first- to fourth-year undergraduates in a cross-section of disciplines studying at a science university in Malaysia. In contrast to the designers, who had 1 to 6 years' professional experience in GUI design, none of these students had been trained in visual design. Irish, Malaysians, experts, and general users potentially represent different attitudes towards the importance of aesthetics in computer systems.

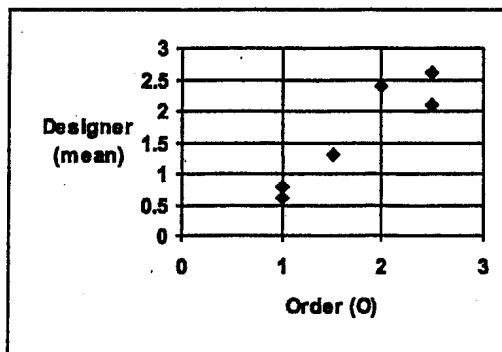110   DAVID CHEK LING NGO, AZMAN SAMSUDIN AND ROSNI ABDULLAH

Fig. 7. Scattergram for data in Table 2.

The procedure used was slightly different from the one used before. The layouts were displayed in a classroom, and the participants rated each layout using a 0 to 3 scale. Participant ratings were averaged to form an aesthetic score for each of the 7 layouts. Mean scores for all 7 layouts were very similar to the findings obtained in the previous study (see

Table 3. Comparison of the two tests.

	L1	L2	L3	L4	L5	L6	L7
O	2.5	2.5	1.0	1.0	2.0	0.5	1.0
Test 1 (Mean)	2.1	2.6	1.3	0.8	2.4	0.6	0.8
Test 2 (Mean)	2.2	2.6	1.8	1.5	2.0	1.4	1.6

Table 3).

Because both groups showed high correlations in their judgments, we merged the data for use in the following analysis. Correlations of the aesthetic values with the corresponding subjects' scores for the two parts of the experiment are presented in Table 4.

Table 4. Correlations of the computed values with the
subjects' scores for the two test.

	Test 1	Test 2	Both
O	0.99	0.96	0.97

Significant relationships were found between the scores the students gave to the layouts and their corresponding values. This impressive result is encouraging. In general, the relationships resemble those obtained before. The results replicate the previous findings. This suggests that aesthetic perceptions are culturally independent. (See [9, 13, 32] for a different opinion.) Relatively high correlation was obtained between these two scales, which suggests that our aesthetic model is somewhat related to non-designers' as well as designers' perceptions of aesthetics. However, the magnitude of correlation between the two

rankings was slightly lower in this experiment. These results are not surprising, given the expectation that scientists would normally be less sensitive to the aesthetic aspects of the interface.

6. AESTHETIC MEASURES IN AN APPLICATION

This section describes an example software system called Visit in which aesthetic measures have been installed as part of a tool used to evaluate screen layouts. Visit, which stands for Visitor Information System Implementation Tool, is a new, experimental design tool for creating hypermedia systems. Visit provides a set of tools that simplify screen design and implementation. Visit offers the user a library of on-screen objects and supports direct-manipulation interaction in the work area. In addition, Visit has a critic system that helps users design screens. It offers criticism, suggestions, and explanations to help users improve their designs through the use of aesthetic measures. Visit was developed as part of Ngo's Ph.D. dissertation while he was at Trinity College, the University of Dublin. A full report on Visit is available [21].

We built a 15-node visitor information system for 14 golf courses in Northern Ireland using Visit. The overall design of the screen layouts and their contents were taken from a promotional brochure produced by the Northern Ireland Tourist Board. The system contains 15 nodes with only two basic designs (Fig. 8 and Fig. 9). The aesthetic values for the designs were poor because they are not in balance or equilibrium, and are asymmetrical. We then proposed two corresponding designs with the help of the critic system (Fig. 10 and Fig. 11). A viewer can make a subjective evaluation of aesthetic preference between the two sets of designs. We believe that the original designs were significantly improved using the Visit approach. Most of the graphic designers we have interviewed agreed with us. Common remarks about the redesigned screens include that they have fewer alignment points, the arrangement of screen objects is ordered and facilitates eye movement patterns, and the use of surrounding white space is efficient.
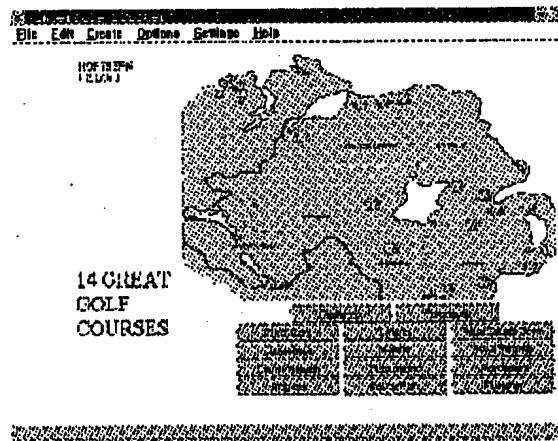

Fig. 8. Original screen.

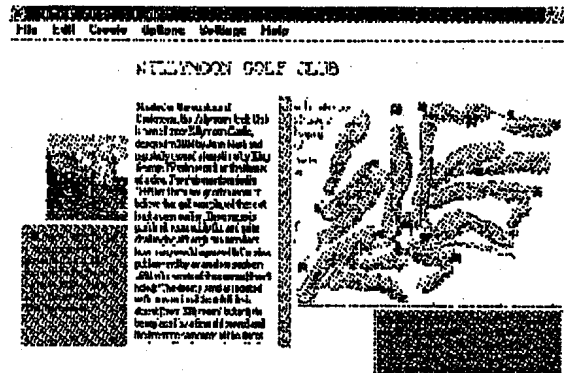112   DAVID CHEK LING NGO, AZMAN SAMSUDIN AND ROSNI ABDULLAH
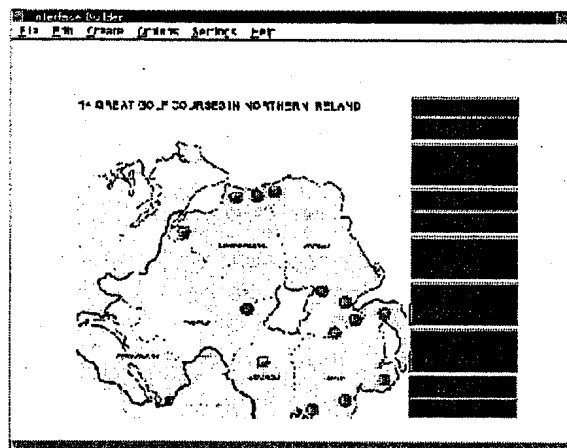

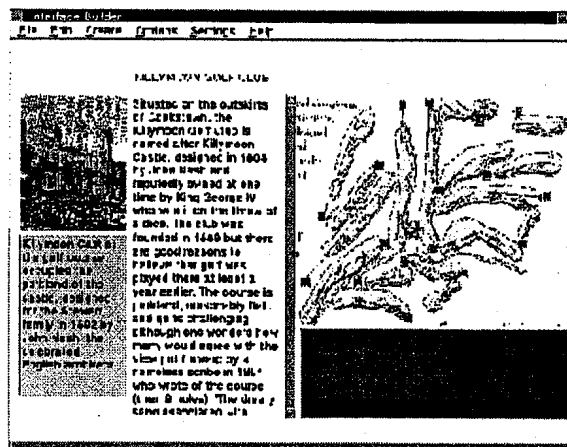Fig. 9. Original screen.

Fig. 10. Redesigned screen.

Fig. 11. Redesigned screen.

7. CONCLUSIONS AND FUTURE WORK

In this article, we have presented a computational theory of interface aesthetics evaluation. Our informal study has suggested that the model is closely related to designers' as well as non-designers' perceptions of aesthetics. We have demonstrated that the aesthetics of screen layouts can be measured objectively. We have also demonstrated that aspects of the theory of aesthetics, such as Birkhoff's aesthetic measure, can be effectively applied to screen design. The application Visit, in which aesthetic measures have been applied, allows the user to create screen layouts directly rather than by working through a designer.

Although the results of the evaluation were sufficiently clear to satisfy the overall objective of the exercise, that is, to make interface design both objective and scientific, they require further development. Much can be done to make the current formulae better, and the study described here has suggested some improvements which can enhance their usability.

First, a designer can control some elements of composition to achieve balance. For instance, color is visually heavier than white; big objects are visually heavier than little objects. The measure of screen balance presented here does not include properties like object type and color, or font type and weight. Second, a layout is in equilibrium when its center corresponds approximately to the center of the frame. Practically speaking, there are however, minor deviations from this definition. Owing to the visual gravitational pull, the balancing center of the layout will lie somewhat higher than the center of the frame, thereby compensating for the greater weight of the area's upper half. But such discrepancies are small. Hence, for equilibrium,

$$EM = (0, y_c - y_o) \qquad \text{(from Eq. 3)}$$

and

$$y' \le (y_c - y_0) \le 0$$

where y' is the optimum level.

Third, as for complexity, which is defined as the number of on-screen objects, we can increase its scope to include, for example, the numbers of typefaces and colors used. Fourth, the measure of sequence is culture dependent since it promotes a reading pattern that is common in Western cultures. Finally, principles may not always be compatible. When incompatibilities are encountered by the viewer, confusion results. As pointed out by a reviewer, from Tables 1-3, we can see that the sensitivity of the measure O used to discriminate between the different layout designs (L1-L7) is low compared to designers' and users' sensitivity. This might be a deficiency of the measure. We are gradually improving our formulae to match the designer. The formulae outlined in this paper are under continuous review and development. This study was concerned only with object organization, which narrowed its focus. For example, in this study, we did not consider properties such as object type. Therefore, this study cannot be regarded in any way as universal and all-inclusive. Cultural and educational differences may influence attitudes towards the importance of aesthetics. We need to create more specially designed analysis packages to analyze these equations. We also need to increase the sensitivity of the experiment by increasing the sample size. Characteristics that are common to the feelings which give one an aesthetic experience should not be limited to the few. More accordant ordering principles with appropriate design conventions must be found if this approach is to be improved.

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